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Testimony of

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Mr. Chairman and members of the Subcommittee. I am Donald M. Anderson, a Senior Scientist in the Biology Department of the Woods Hole Oceanographic Institution, where I have been active in the study of red tides and harmful algal blooms (HABs) for 25 years. I am here to provide the perspective of an experienced scientist who has investigated many of the harmful algal bloom (HAB) phenomena that affect coastal waters of the United States and the world. I am also Director of the U.S. National Office for Marine Biotoxins and Harmful Algal Blooms, and have been actively involved in formulating the scientific framework and agency partnerships that support and guide our national program on HABs. Thank you for the opportunity to acquaint you with the national problem of HABs, the present status of our research progress, and the future actions that are needed to maintain and expand this vibrant and important national program.

BACKGROUND

Among the thousands of species of microscopic algae at the base of the marine food chain are a few dozen which produce potent toxins. These species make their presence known in many ways, sometimes as a massive "bloom" of cells that discolor the water, sometimes as dilute, inconspicuous concentrations of cells noticed only because they produce highly potent toxins which either kill marine organisms directly, or transfer through the food chain, causing harm at multiple levels. The impacts of these phenomena include mass mortalities of wild and farmed fish and shellfish, human intoxications or even death from contaminated shellfish or fish, alterations of marine trophic structure through adverse effects on larvae and other life history stages of commercial fisheries species, and death of marine mammals, seabirds, and other animals.

Blooms of toxic algae are commonly called "red tides," since the tiny plants sometimes increase in abundance until they dominate the planktonic community and tint the water with their pigments. The term is misleading, however, since toxic blooms may be greenish or brownish; non-toxic species can bloom and harmlessly discolor the water; and, conversely, adverse effects can occur when some algal cell concentrations are low and the water is clear. Given the confusion, the scientific community now uses the term "harmful algal bloom" or HAB.

HAB phenomena take a variety of forms. With regard to human health, the major category of impact occurs when toxic phytoplankton are filtered from the water as food by shellfish which then accumulate the algal toxins to levels that can be lethal to humans or other consumers. These poisoning syndromes have been given the names paralytic, diarrhetic, neurotoxic, azaspiracid, and amnesic shellfish poisoning (PSP, DSP, NSP, AZP, and ASP). All have serious effects, and some can be fatal. Except for ASP, all are caused by biotoxins synthesized by a class of marine algae called dinoflagellates. ASP is produced by diatoms that until recently were all thought to be free of toxins and generally harmless. A sixth human illness, ciguatera fish poisoning (CFP) is caused by biotoxins produced by dinoflagellates that grow on seaweeds and other surfaces in coral reef communities. Ciguatera toxins are transferred through the food chain from herbivorous reef fishes to larger carnivorous, commercially valuable finfish. Another human illness linked to toxic algae is called Possible Estuary-Associated Syndrome (PEAS). This vague term reflects the poor state of knowledge of the human health effects of the dinoflagellate *Pfiesteria piscicida* and related organisms that have been linked to symptoms such as deficiencies in learning and memory, skin lesions, and acute respiratory and eye irritation – all after exposure to estuarine waters where *Pfiesteria*-like organisms have been present (Burkholder and Glasgow, 1997). Yet another human health impact from HABs occurs when a class of algal toxins called the brevetoxins becomes airborne in sea spray, causing respiratory irritation and asthma-like symptoms in beachgoers and coastal residents, typically along the shores of the Gulf of Mexico. The documented effects are acute in nature, but studies are underway to determine if there are also long-term consequences of toxin inhalation.

Distribution of HAB Phenomena in the United States. With the exception of DSP and AZP, all of the poisoning syndromes described above are known problems within the U.S. and its territories, affecting large expanses of coastline (Fig. 1). PSP occurs in all coastal New England states as well as New York, extending to offshore areas in the northeast, and along much of the west coast from Alaska to northern California. Overall, PSP affects more U.S. coastline than any other algal bloom problem. NSP occurs annually along Gulf of Mexico coasts, with the most frequent outbreaks along western Florida and Texas. Louisiana, Mississippi, North Carolina and Alabama have also been affected intermittently, causing extensive losses to the oyster industry and killing birds and marine mammals. ASP has been a problem for all of the U.S. Pacific coast states. The ASP toxin has been detected in shellfish on the east coast as well, and in plankton from Gulf of Mexico waters. Human health problems from *Pfiesteria* species (PEAS) are thus far poorly documented, but have affected laboratory workers, fishermen, and others working in or exposed to estuarine waters in several portions of the southeastern U.S. CFP is the most frequently reported non-bacterial illness associated with eating fish in the U.S. and its territories, but the number of cases is probably far higher, because reporting to the U.S. Center for Disease Control is voluntary and there is no confirmatory laboratory test. In the Virgin Islands, nearly 50% of the adults are estimated to have been poisoned at least once, and some estimate that 20,000 – 40,000 individuals are poisoned by ciguatera annually in Puerto Rico and the U.S. Virgin Islands alone. CFP occurs in virtually all sub-tropical to tropical U.S. waters (i.e., Florida, Hawaii, Guam, Virgin Islands, Puerto Rico, and many Pacific Territories). As tropical fish are increasingly exported to distant markets, ciguatera has become a worldwide problem.

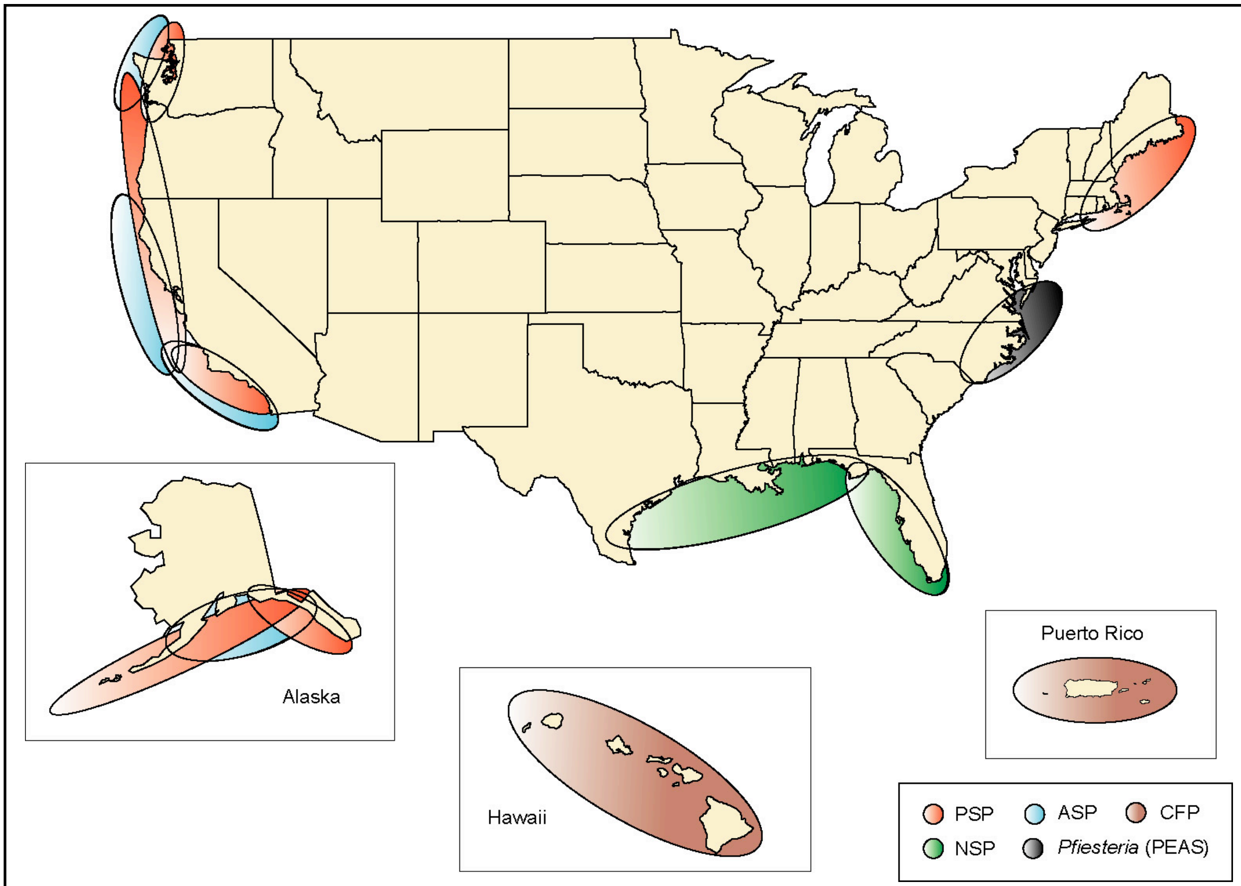

Figure 1. Distribution of HAB phenomena responsible for human illnesses in the U.S. (Source: U.S. National Office for Marine Biotoxins and Harmful Algal Blooms.)

Economic and Societal Impacts. HABs have a wide array of economic impacts, including the costs of conducting routine monitoring programs for shellfish and other affected resources, short-term and permanent closure of harvestable shellfish and fish stocks, reductions in seafood sales (including the avoidance of "safe" seafoods as a result of over-reaction to health advisories), mortalities of wild and farmed fish, shellfish, submerged aquatic vegetation and coral reefs, impacts on tourism and tourism-related businesses, and medical treatment of exposed populations. A conservative estimate of the average annual economic impact resulting from HABs in the U.S. is approximately $50 million (Anderson et al., 2000; Hoagland et al., 2002). Cumulatively, the costs of HABs exceed a billion dollars over the last several decades. These estimates do not include the application of "multipliers" that are often used to account for the manner in which money transfers through a local economy. With multipliers, the estimate of HAB impacts in the United States easily exceeds $100 million per year. Individual bloom events can equal or exceed the annual average, as occurred for example in 1997 when fish kills associated with blooms of *Pfiesteria* occurred on Maryland's eastern shore. Consumers avoided all seafood from the region, despite assurances that no toxins had been detected in any seafood products. The aggregate impact from this single event (including lost seafood sales and revenues for recreational boat charters) was $50 million.

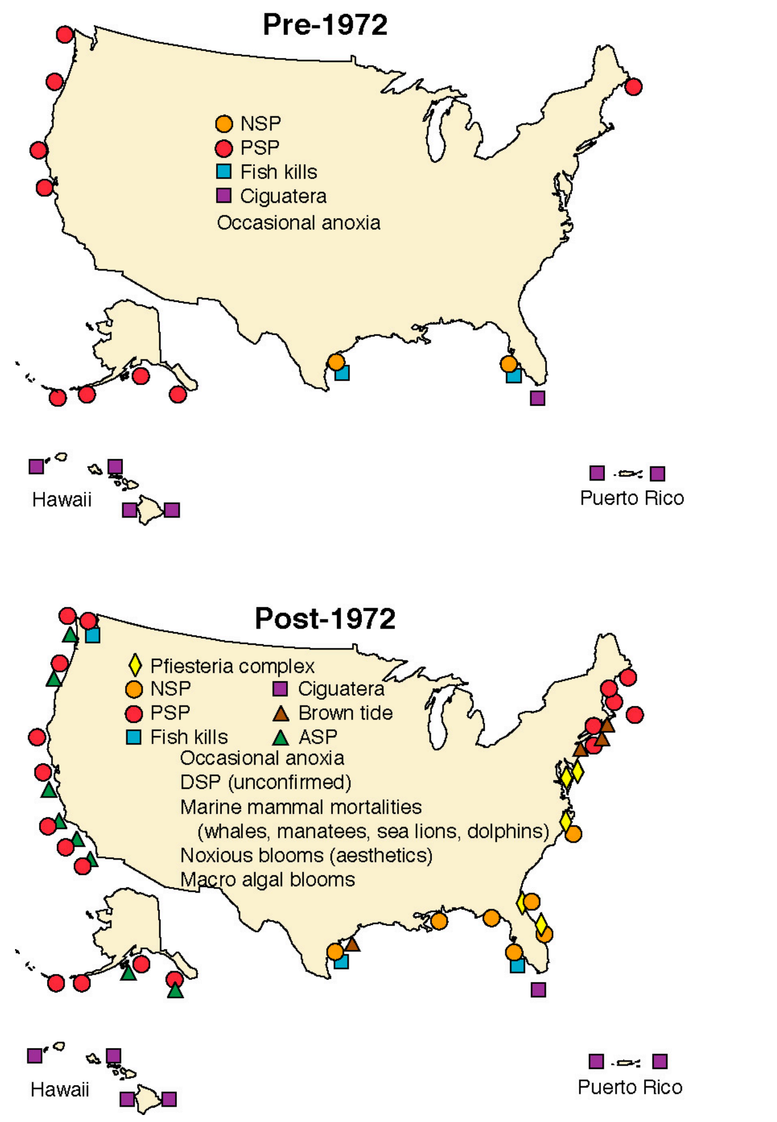

Figure 2. Expansion of HAB outbreaks over the past 30 years in the U.S. (Source: U.S. National Office for Marine Biotoxins and Harmful Algal Blooms.

Recent Trends. The nature of the HAB problem has changed considerably over the last three decades in the U.S. Virtually every coastal state is now threatened by harmful or toxic algal species, whereas 30 years ago, the problem was much more scattered and sporadic (Fig. 2.). The number of toxic blooms, the economic losses from them, the types of resources affected, and the number of toxins and toxic species have all increased dramatically in recent years in the U.S. and around the world (Anderson, 1989; Hallegraeff, 1993).

The first thought of many is that pollution or other human activities are the main reason for this expansion, yet in the U.S.

at least, many of the "new" or expanded HAB problems have occurred in waters where pollution is not an obvious factor. Some new bloom events likely reflect indigenous populations that have been discovered because of better detection methods and more observers rather than new species introductions or dispersal events (Anderson, 1989).

Other "spreading events" are most easily attributed to dispersal via natural currents, while it is also clear that man may have contributed to the global HAB expansion by transporting toxic species in ship ballast water (Hallegraeff and Bolch, 1992). The U.S. Coast Guard, EPA, and the International Maritime Organization are all working toward ballast water control and treatment regulations that will attempt to reduce the threat of species introductions worldwide.

Another factor underlying the global expansion of HABs is the dramatic increase in aquaculture activities. This leads to increased monitoring of product quality and safety, revealing indigenous toxic algae that were probably always present (Anderson 1989). The construction of aquaculture facilities also places fish or shellfish resources in areas where toxic algal species occur but were previously unknown, leading to mortality events or toxicity outbreaks that would not have been noticed had the aquaculture facility not been placed there.

Of considerable concern, particularly for coastal resource managers, is the potential relationship between the apparent increase in HABs and the accelerated eutrophication of coastal waters due to human activities (Anderson et al., 2002). As mentioned above, some HAB outbreaks occur in pristine waters with no influence from pollution or other anthropogenic effects, but linkages between HABs and eutrophication have been frequently noted within the past several decades (e.g., Smayda, 1990). Coastal waters are receiving massive and increasing quantities of industrial, agricultural and sewage effluents through a variety of pathways. In many urbanized coastal regions, these anthropogenic inputs have altered the size and composition of the nutrient pool which may, in turn, create a more favorable nutrient environment for certain HAB species. Just as the application of fertilizer to lawns can enhance grass growth, marine algae can grow in response to various types of nutrient inputs. Shallow and restricted coastal waters that are poorly flushed appear to be most susceptible to nutrient-related algal problems (Fig. 3). Nutrient enrichment of such systems often leads to eutrophication and increased frequencies and

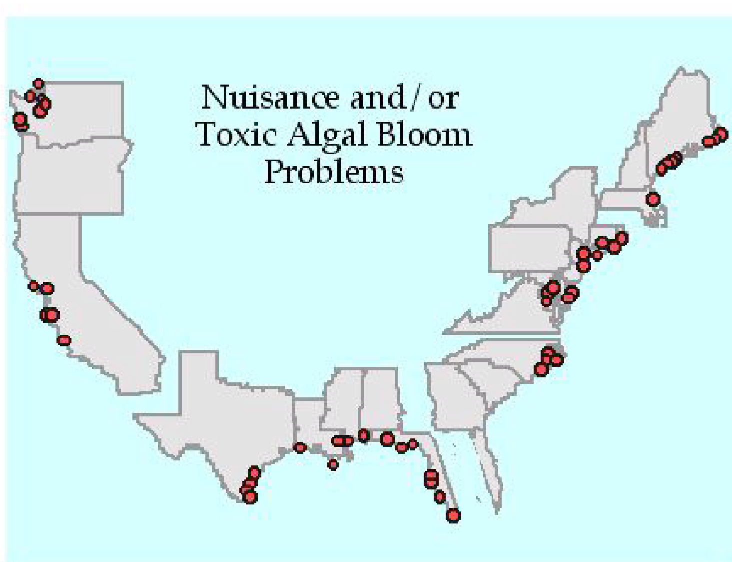

Figure 3. U.S. estuaries with reported moderate to high levels of nuisance or toxic blooms, cited as symptoms of high eutrophic conditions. (Source: S.B. Bricker, NOAA.).

magnitudes of phytoplankton blooms, including HABs. There is no doubt that this is true in certain areas of the world where pollution has increased dramatically. It is perhaps real, but less evident in areas where coastal pollution is more gradual and unobtrusive.

It is now clear that the worldwide expansion of HAB phenomena is in part a reflection of our ability to better define the boundaries of an existing problem. Those boundaries are also expanding, however, due to natural species dispersal via storms or currents, as well as to human-assisted species dispersal, and enhanced HAB population growth as a result of pollution or other anthropogenic influences. The fact that part of the expansion is a result of increased awareness should not temper our concern. The HAB problem in the U.S. is serious, large, and growing. It is a much larger problem than we thought it was a decade or more ago.

PROGRESS AND STATUS OF OUR NATIONAL PROGRAM ON HABS

For many years, U.S. researcher and coastal managers recognized, but struggled through piecemeal and fragmented efforts, to address the problems of HABs. Now, however, elements of a national program on HABs have been formulated and implemented at a scale that has clearly had a significant impact on our understanding of these phenomena and our ability to manage their impacts. A pivotal planning document entitled *Marine Biotoxins and Harmful Algae: A National Plan* (Anderson et al., 1993) identified numerous impediments to progress in the HAB field and made specific recommendations to address those impediments. These impediments have been addressed to varying degrees with funding programs targeting specific topic areas within the broad field of HABs and their impacts. In 1994, NSF, together with NOAA, co-sponsored a workshop on the Ecology and Oceanography of Harmful Algae. The participants, a group of 40 academic and government scientists, and program officers from numerous federal agencies attended and developed a coordinated research strategy. The resulting plan, *ECOHAB: The Ecology and Oceanography of Harmful Algal Blooms: A National Research Agenda* (Anderson 1995) provided the framework needed to increase our understanding of the fundamental processes underlying the impacts and population dynamics of HABs. This involved a recognition of the many factors at the organismal level that determine how HAB species respond to, and potentially alter their environment, the manner in which HAB species affect or are affected by food-web interactions, and how the distribution, abundance, and impact of HAB species are regulated by the environment.

The ECOHAB Program identified major research themes that encompass national priorities on HAB phenomena. It was subsequently established as a competitive, peer-reviewed research program supported by an interagency partnership involving NOAA, NSF, EPA, ONR, and NASA. Research results have been applied through another program, Monitoring and Event Response (MERHAB) to foster innovative monitoring programs and rapid response by public agencies and health department to safeguard public health, local economies, and fisheries.

Projects funded through ECOHAB include regional studies on the biogeochemical, ecological, and physical processes that contribute to bloom formation and maintenance, and individual targeted studies that examine specific biological and physical processes that regulate the occurrence of specific HABs. Large, multi-investigator regional ECOHAB studies have been undertaken in the Gulf of Maine for paralytic shellfish poisoning, the Gulf of Mexico for fish kills, aerosolized toxins and neurotoxic shellfish poisoning, the shallow bays and lagoons of eastern Long Island for destructive brown tides, the mid-Atlantic states for *Pfiesteria* and related organisms, and, more recently, the U.S. west coast for *Pseudo-nitzschia* and domoic acid poisoning and Hawaii for macroalgal (seaweed) overgrowth. In addition, several dozen smaller research projects have been initiated in many states and regions, covering a wide array of HAB organisms and topics.

RESEARCH AND MANAGEMENT PROGRESS

With the advent of ECOHAB, MERHAB, and other national HAB programs, resources have been directed towards the goal of scientifically based management of coastal waters and fisheries that are potentially impacted by HABs. These programs are little more than five years old, but they have already made a significant contribution to HAB management capabilities in the U.S. Here I will highlight advances in our understanding of HAB phenomena, as well as some of the program-derived technological developments that are providing new tools to coastal resource managers in regions impacted by HABs.

Enhanced understanding of HAB dynamics

In areas studied by the multi-investigator ECOHAB-funded regional research projects, HAB phenomena are now far better understood than was the case just 5 years ago when the program began. Knowledge is also increasing for HABs in other areas through smaller, targeted research projects, but at a slower pace because of the lower investment of resources. In the Gulf of Maine, the focus of the ECOHAB-GOM program, the probable origins of toxic *Alexandrium* cells responsible for PSP outbreaks have been identified by mapping the locations of dormant resting cysts in bottom sediments. Cysts in several accumulation zones or "seedbeds" germinate in the spring and re-populate the water column with swimming *Alexandrium* cells, which then multiply and cause the annual PSP outbreaks. A large cyst accumulation zone in the Bay of Fundy, in conjunction with a hydrographic feature called an "eddy" that retains bloom cells near the mouth of the Bay are now known to be critical in the *Alexandrium* dynamics for the <u>entire</u> Gulf of Maine region. This is because the retained bloom can serve as the "incubator" or source for cells that ultimately escape the Bay and enter the coastal waters of Maine, where they proliferate as they are transported along the coast. Those cells that do remain in the Bay form the new cysts that fall to bottom sediments and are then available to start new blooms in subsequent years. In this manner, the recurrent, self-seeding and "propagating" nature of the regional PSP blooms has been elucidated. ECOHAB-GOM researchers also discovered large concentrations of toxic *Alexandrium* cells in deeper, offshore waters, and demonstrated the mechanisms by which these blooms form and are intermittently delivered to shore and the intertidal shellfish. Before the program began, these offshore populations were unknown, and researchers had assumed that *Alexandrium* populations in shallow waters were largely responsible for the observed shellfish toxicity.

In the Gulf of Mexico, the ECOHAB-Florida program identified similar transport and delivery mechanisms for the toxic *Karenia* cells that kill fish and cause many other problems in the coastal zone. In particular, the *Karenia* cells are now thought to be transported onshore in deeper waters through wind events that cause "upwelling". Special bathymetric features of the ocean bottom can facilitate this transport and focus cell delivery to areas known to be the sites of recurrent blooms. Studies of nutrient uptake by *Karenia* suggest a fascinating link between red tide blooms and dust storms from the Sahara. These dust clouds travel across the Atlantic and deposit dust into Gulf of Mexico waters, stimulating the growth of a different kind of algae called *Trichodesmium* that then releases nutrients in a form that *Karenia* can utilize. This is a complex, multi-step and multi-organism interaction leading to *Karenia* blooms, but there are a number of supporting datasets that support the hypothesized linkages. Related studies are suggesting that the ultimate demise of the Florida *Karenia* blooms is a lack of phosphorus. This has obvious implications to policy decisions concerning pollution and water quality in the region.

Consistent with the identification of "source regions" for Gulf of Maine and Gulf of Mexico HABs, researchers in the Pacific Northwest have identified an area west of Puget Sound (another eddy) that appears to accumulate toxic diatoms responsible for outbreaks of amnesic shellfish poisoning (ASP), a debilitating illness that includes permanent loss of short-term memory in some victims. Other programs have been equally productive in identifying underlying driving mechanisms for HAB blooms, such as the Brown Tide Research Initiative that focused resources on brown tide blooms in New York and New Jersey. These dense accumulations of tiny *Aureococcus anophagefferens* cells turn the water a deep brown, blocking sunlight to submerged vegetation, and altering the feeding behavior of shellfish. These blooms have been linked to certain types of nutrients that seem to favor the causative organism – in particular "organic" forms of nitrogen that are preferred by the brown tide cells, and give it a competitive advantage in certain locations.

Research has also revealed a great deal about the *Pfiesteria* blooms that periodically affect the southeast states. Here again, certain nutrient conditions seem to favor *Pfiesteria* blooms, especially those associated with chicken and hog farming operations. Identification of the *Pfiesteria* toxin(s) continues to be elusive, but serious health effects have been documented among humans and laboratory animals exposed to bloom waters, and the list of species linked to fish kills and possible human health effects has grown considerably through the regional research efforts.

These are but a few of the advances in understanding that have accrued from the past 5 years of funding support at the national level. Equally important are the discoveries that provide management tools to reduce the impacts of HABs on coastal resources. Management options for dealing with the impacts of HABs include reducing their incidence and extent (prevention), stopping or containing blooms (control), and minimizing impacts (mitigation). Where possible, it is preferable to prevent HABs rather than to treat their symptoms. Since increased pollution and nutrient loading may enhance the growth of some HAB species, these events may be prevented by reducing pollution inputs to coastal waters, particularly industrial, agricultural, and domestic effluents high in plant nutrients. This is especially important in shallow, poorly flushed coastal waters that are most susceptible to nutrient-related algal problems (Fig. 3). As mentioned above, research on the links between certain HABs and nutrients has highlighted the importance of non-point sources of nutrients (e.g., from agricultural activities, fossil-fuel combustion, and animal feeding operations). Outbreaks of *Pfiesteria* in the Chesapeake Bay and the Neuse-Pamlico estuary in North Carolina have been linked to wastes from chicken and hog farming operations. This in turn has led to policy changes that have been enacted in these watersheds to control these non-point sources. In these instances, agency officials faced with these controversial policy decisions were provided with scientific justification for nutrient reductions that derived from research through ECOHAB and other programs.

The most effective HAB management tools are monitoring programs that involve sampling and testing of wild or cultured seafood products directly from the natural environment, as this allows unequivocal tracking of toxins to their site of origin and targeted regulatory action. Numerous monitoring programs of this type have been established in U.S. coastal waters, typically by state agencies. This monitoring has become quite expensive, however, due to the proliferation of toxins and potentially affected resources. States are heavily struggling with flat or declining budgets versus the need to monitor for a growing list of HAB toxins and potentially affected fisheries resources. Technologies are thus urgently needed to facilitate the detection and characterization of HAB cells and blooms.

One very useful technology that has been developed through recent HAB research relies on species- or strain-specific "probes" that can be used to label only the HAB cells of interest so they can then be detected visually, electronically, or chemically. These probes can be in the form of antibodies that bind to specific proteins on the cell surface of the targeted HAB species, or they can be short segments of synthetic DNA that bind to particular genes or gene transcripts inside the HAB cells. Progress has been rapid and probes of several different types are now available for many of the harmful algae, along with techniques for their application in the rapid and accurate identification, enumeration, and isolation of individual species. One example of the direct application of this technology in operational HAB monitoring is for the New York and New Jersey brown tide organism, *Aureococcus anophagefferens*. The causative organism is so small and non-descript that it is virtually impossible to identify and count cells using traditional microscopic techniques. Antibody probes were developed that bind only to *A. anophagefferens* cells, and these are now used routinely in monitoring programs run by state and local authorities, greatly improving counting time and accuracy.

Through ECOHAB, MERHAB, and other programs, probes are being incorporated into a variety of different assay systems, including some that can be mounted on buoys and left unattended while they robotically sample the water and test for HAB cells. Clustered with other instruments that measure the physical, chemical, and optical characteristics of the water column, information can be collected and used to make "algal forecasts" of impending toxicity. These instruments are taking advantage of advances in ocean optics, as well as the new molecular and analytical methodologies that allow the toxic cells or chemicals (such as HAB toxins) to be detected with great sensitivity and specificity. A clear need has been identified for improved instrumentation for HAB cell and toxin detection, and additional resources are needed in this regard. This can be accomplished during development of an integrated Ocean Observing System for U.S. coastal waters, and through a targeted research program on HAB prevention, control, and mitigation. These are needed if we are to achieve our vision of future HAB monitoring and management programs – an integrated system that includes arrays of moored instruments as sentinels along the U.S. coastline, detecting HABs as they develop and radioing the information to resource managers.

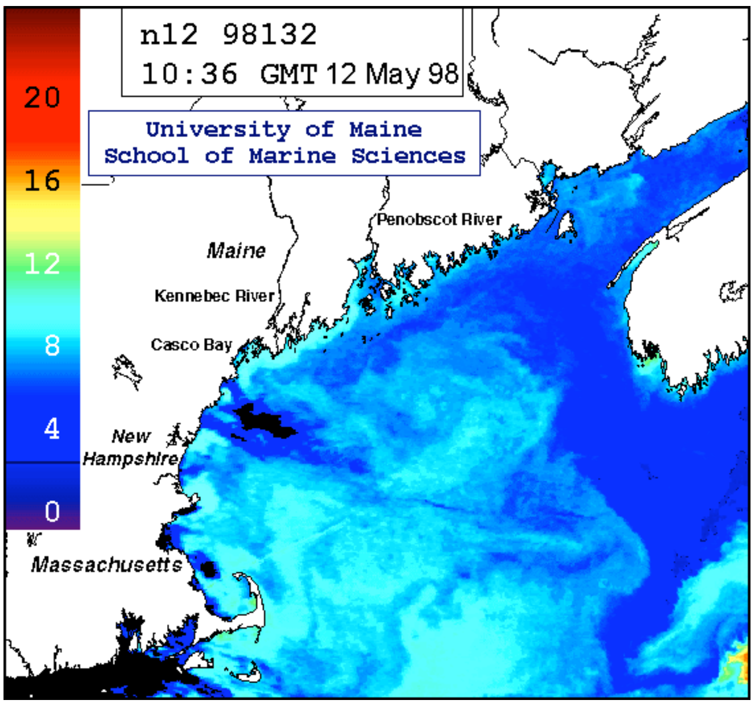

Figure 4. Satellite image of sea surface temperature during an outbreak of paralytic shellfish poisoning toxicity in the Gulf of Maine on May 12, 1998. During persistent northeast winds, cold water (dark black) along the eastern Maine coastline (termed the Eastern Maine Coastal Current) intruded into the western GOM adjacent to the warmer (light grey) buoyant waters emanating from the Penobsot and Kennebec Rivers. Despite clouds (black feature south of Casco Bay) that obscure an area of the western Maine coast, the colder water can be seen impacting the shore at several locations along the western Maine, New Hampshire, and northern Massachusetts coastlines. Shellfish toxicity increased rapidly at these locations during this time, indicative of the delivery of established blooms of toxic *Alexandrium* cells with the coastal current waters. This type of remote sensing information can be of great use to resource managers in forecasting impending toxicity. (Source: A. Thomas, U. Maine).

Another type of cell or bloom detection is possible using remote sensing data from satellites. This has great potential in monitoring the development and movement of blooms over larger spatial and shorter time scales than those accessible through ship- or land-based sampling. There is great promise in the use of both ocean color and sea surface temperature sensors in this regard, but considerable work is needed to bring this potential to fruition in the coastal waters where HABs occur. As demonstrated in the ECOHAB-Gulf of Maine research program, satellite images based on sea surface temperature are proving useful in tracking water masses that impinge on coastal shellfish beds, carrying toxic algae that can quickly render those shellfish dangerous to human consumers (Fig. 4). Likewise, satellite images of ocean color are now used in the Gulf of Mexico to detect and track toxic red tides of *Karenia* *brevis*. Based on research results from the ECOHAB-Florida program, bloom forecast bulletins are now being provided to affected states in the Gulf of Mexico by the NOAA National Ocean Service Center for Coastal Monitoring and Assessment. The bulletins (see http://coastwatch.noaa.gov/hab) are based on the integration of several data sources: satellite ocean color imagery; wind data from coastal meteorological stations; field observations of bloom location and intensity provided by the states of Florida and Texas; and weather forecasts from the National Weather Service. The combination of warning and rapid detection is a significant aid to the Gulf states in responding to these blooms.

A long-term goal of HAB monitoring programs is to develop the ability to forecast or predict bloom development and movement. Prediction of HAB outbreaks requires physical/biological coupled numerical models which account for both the growth and behavior of the toxic algal species, as well as the movement and dynamics of the surrounding water. Numerical models of coastal circulation are advancing rapidly in the U.S., and a number of these are beginning to incorporate HAB dynamics as well. A model developed to simulate the dynamics of the organism responsible for paralytic shellfish poisoning (PSP) outbreaks in the Gulf of Maine is relatively far advanced in this regard, and is now being transitioned from academic use towards an operational mode. A similar model is under development for Gulf of Mexico HABs. Considerable work remains before PSP or Florida red tide forecasts are truly operational for coastal resource management purposes, but progress has been rapid as a result of ECOHAB support, and prospects are bright.

Other practical strategies to mitigate the impacts of HAB events include: regulating the siting of aquaculture facilities to avoid areas where HAB species are present, modifying water circulation for those locations where restricted water exchange is a factor in bloom development, and restricting species introductions (e.g., through regulations on ballast water discharges or shellfish and finfish transfers for aquaculture). Each of these strategies requires fundamental research such as that being conducted in our national HAB program. Potential approaches to directly control or suppress HABs are under development as well - similar to methods used to control pests on land – e.g., biological, physical, or chemical treatments that directly target the bloom cells. One example is work conducted in my own laboratory, again through ECOHAB support, using ordinary clay to control HABs. When certain clays are dispersed on the water surface, the tiny clay particles aggregate with each other and with other particles, including HAB cells. The aggregates then settle to the ocean bottom, carrying the unwanted HAB cells from the surface waters where they would otherwise grow and cause harm. As with many other new technologies for HABs, initial results are quite promising and small-scale field trials are underway, but continued support is needed to fully evaluate benefits, costs, and environmental impacts.

Another intriguing bloom control strategy is being evaluated for the brown tide problem. It has been suggested that one reason the brown tides appeared about 15-20 years ago was that hard clams and other shellfish stocks have been depleted by overfishing in certain areas. Removal of these resources altered the manner in which those waters were "grazed" - i.e., shellfish filter large quantities of water during feeding, and that removes many microscopic organisms from the water, including natural predators of the brown tide cells. If this hypothesis is valid, a logical bloom control strategy would be to re-seed shellfish in the affected areas, and to restrict harvesting. Pilot projects are now underway to explore this control strategy in Long Island.

In general, bloom control is an area where very little research effort has been directed in the U.S. (Anderson 1997), and considerable research is needed before these means are used to control HABs in natural waters given the high sensitivity for possible damage to coastal ecosystem and water quality by the treatments. As discussed below, this could be accomplished as part of a national program on HAB prevention, control, and mitigation.

PROGRAMMATIC NEEDS

The support provided to HAB research through ECOHAB, MERHAB, Sea Grant, and other national programs has had a tremendous impact on our understanding of HAB phenomena, and on the development of management tools and strategies. Funding for ECOHAB is modest, but it is administered in a scientifically rigorous manner that maximizes research progress. Several 5-year ECOHAB regional research projects are winding down, and new ones are beginning in other regions. This is an equitable way to share resources nationally, but it assumes that 5 years of funding is all that is needed to understand and mitigate the regional HAB problems, and this is certainly not the case. HAB phenomena are complex oceanographic phenomena, and a decade or more of targeted research are needed for each of the major poisoning syndromes or regions. ECOHAB support for regional studies must be sustained and expanded, and this will require a commitment of resources well in excess of those currently available. Underlying this recommendation is the recognition that we need to form multiple skilled research teams with the equipment and facilities required to attack the complex scientific issues involved in HAB phenomena. Since HAB problems facing the U.S. are diverse with respect to the causative species, the affected resources, the toxins involved, and the oceanographic systems and habitats in which the blooms occur, we need multiple teams of skilled researchers and managers distributed throughout the country. This argues against funding that ebbs and floods with the sporadic pattern of HAB outbreaks or that focuses resources in one region while others go begging. **I cannot emphasize too strongly the need for an equitable distribution of resources that is consistent with the scale and extent of the national problem, and that is sustained through time.** This is the only way to keep research teams intact, forming the core of expertise and knowledge that leads to scientific progress. To achieve this balance, we need a scientifically based allocation of resources, not one based on political jurisdictions. This is possible if we work within the guidelines of the *National Plan* and with the inter-agency effort that has been guiding its implementation.

ECOHAB cannot address all of the HAB research needs, so we also envision a parallel series of programs which focus on other aspects of the national problem. The following HAB programs are either ongoing, or planned at the national level.

Oceans and Human Health. One that is currently being implemented recognizes the important links between oceans and human health, and in particular, the emergence of HABs as recurrent and serious threats in this regard. This focus is entirely complementary to the ecology and oceanography focus of ECOHAB. The first step towards a comprehensive program in this area is a partnership between the National Institute of Environmental Health Sciences (NIEHS) and NSF's Ocean Sciences Division called Centers for Oceans and Human Health (COHH) (NIEHS and NSF, 2002). In general terms, this program is intended to provide linkages between members of the ocean sciences and biomedical communities through support of interdisciplinary research in areas where improved understanding of marine processes and systems has potential to reduce public health risks and enhance existing biomedical capabilities. HABs are one of the three research areas receiving special emphasis in this program, and research needs have been identified in such areas as toxin genetics, biosynthesis and function, and human exposure and effect assessment, among many others. In its initial phase, four OHH centers will be created, but this is far from the number that would ultimately be needed for an efficient national network. Sustained and increased support for the COHH program will be of great value to the HAB National Plan. The partnership between NIEHS and NSF clearly needs to be expanded in order to provide support to a network of sufficient size to address the significant problems under the COHH umbrella. This is best accomplished through additional funds to these agencies, as well as through the involvement of other agencies with interests in oceans and human health, including, for example, NOAA, EPA, NASA, and CDC. In this context, it is of note that NOAA's FY03 appropriation includes an item for Oceans and Human Health under NOAA's Ocean Health Initiative. Since this is in the Ocean and Coastal Partnership Programs section of the budget, it represents a wonderful opportunity for inter-agency cooperation on a very important program. I would emphasize the need to allocate these NOAA funds through a peer-reviewed, competitive, extramural effort coordinated with other national HAB programs, including ECOHAB, MERHAB, and especially the NIEHS/NSF COHH initiative. These latter two agencies have taken the lead in this topic area, and their commitment to high-quality science and willingness to cooperate speak strongly for the important role they could play in coordinating such an interagency partnership. Another OHH need is for interdisciplinary training of the scientists working on oceans and human health issues, since an educational element is not addressed in the NIEHS/NSF COHH program at present. We also need targeted funds for research on OHH themes, separate from the funds supporting the Centers, as well as for Study Sections or review panels that are appropriately constituted to review NSF and NIEHS applications in the OHH field. At present, the existing Study Sections and panels do not have the requisite expertise and mandate to address funding priorities for OHH topics.

Prevention, Control and Mitigation. Looking again to the *National Plan*, it is apparent that other funding initiatives are needed to address program elements that are not covered by the ECOHAB, MERHAB and OHH programs. It will thus be necessary to convene focused workshops to refine and develop key issues to the levels needed by program managers to define specific programs - an approach analogous to that used to produce the ECOHAB science agenda (Anderson 1995). One such workshop has already been held, and a science plan for a program on *Prevention, Control, and Mitigation of Harmful Algal Blooms* published by Sea Grant (Cammen et al., 2001). The rationale for this program is that much of the focus of past HAB research has been on fundamental aspects of organism physiology, ecology, and toxicology, so little effort has been made to address more practical issues such as bloom prediction, resource management strategies, or even direct bloom control (Anderson 1997). A funding program focusing on these practical aspects of HAB management is thus needed, as recommended by experts and resource managers in a report by Boesch et al. (1997). Funds intended for ecological, toxicological, epidemiological, or oceanographic studies (e.g., ECOHAB, COHH) should not be diverted to a new initiative on prevention, control and mitigation, as many mechanisms and processes remain poorly understood. New, targeted funds are necessary.

A U.S. – European Union program on HABs. For decades, HABs have been studied on both sides of the Atlantic, but largely in separate, isolated research programs. For the first time, joint research in Europe and the U.S. is being considered to address these problems of mutual concern, through financial support from the European Commission (E.C.) and the U.S. National Science Foundation (NSF). It is now well recognized and accepted that our understanding of the population dynamics of organisms, their impacts, and the potential management implications, is dependent on working within a global arena. Although HAB impacts may be local, solutions may be found in distant locales. In recognition of the importance of scientific collaboration among nations, the European Commission and the U.S. National Science Foundation signed an agreement in October 2001 to foster such collaboration, and HABs were highlighted as one of the scientific areas of collaboration under this agreement.. A workshop was recently convened to bring together scientists from both sides of the Atlantic to collectively assess the state of the science, to identify gaps in our knowledge, and to develop an international plan for cooperative, comparative studies. A plan has been formulated and is currently being finalized and evaluated by agency officials and scientists in the E.U. and the U.S. Support in this type of bilateral program should be a high priority in the future, and multi-national efforts such as the Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) program should be supported as well.

SUMMARY AND RECOMMENDATIONS

The diverse nature of HAB phenomena and the hydrodynamic and geographic variability associated with different outbreaks throughout the U.S. pose a significant constraint to the development of a coordinated national HAB program. Nevertheless, the combination of planning, coordination, and a highly compelling topic with great societal importance has initiated close cooperation between officials, government scientists and academics in a sustained attack on the HAB problem. The rate and extent of progress from here will depend upon how well the different federal agencies continue to work together, and on how effectively the skills and expertise of government and academic scientists can be targeted on priority topics that have not been well represented in the national HAB program. The opportunity for cooperation is clear, since as stated in the ECOHAB report (Anderson 1995), "Nowhere else do the missions and goals of so many government agencies intersect and interact as in the coastal zone where HAB phenomena are prominent." The HAB community in the U.S. has matured scientifically and politically, and is fully capable of undertaking the new challenges inherent in an expanded national program. This will be successful only if a coordinated interagency effort can be implemented to focus research personnel, facilities, and financial resources to the common goals of a comprehensive national strategy.

In summary:

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- HABs are a serious and growing problem in the U.S., affecting every coastal state. HABs impact public health, fisheries, aquaculture, tourism, and coastal aesthetics. HAB problems will not go away and will likely increase in severity.
- A coordinated National HAB Program has been formulated and partially implemented, but additional program elements need to be implemented, especially those directly addressing public health and prevention, control, and mitigation issues.
- State agencies are doing an excellent job protecting public health and fisheries, but those monitoring programs are facing growing challenges. Needs for the future include new technologies for HAB monitoring and forecasting and incorporation of these tools into regional Ocean Observing Systems.
- HABs are just one of many problems in the coastal zone that are affected by nutrient inputs and over-enrichment from land. They represent a highly visible indicator of the health of our coastal ocean. More subtle impacts to fisheries and ecosystems are likely occurring that are far more difficult to discern.

Recommendations:

- Sustain and enhance support for the national HAB program
    - Sustain and enhance support for the ECOHAB, MERHAB and OHH programs, and implement new programs, such as Prevention, Control and Mitigation of HABs and the E.U. –U.S. Program on HABs
    - Encourage interagency partnerships, as the HAB problem transcends the resources or mandate of any single agency
- Support methods and instrument development for land- and mooring-based cell and toxin detection, and for bloom forecasting (e.g., through a program on HAB Prevention, Control and Mitigation and through instrument development support for the Ocean Observing System).
- Incorporate HAB monitoring into an integrated U.S. Ocean Observing System
- Support long-term water quality and HAB monitoring programs in coastal waters
- Implement agriculture and land-use policies that reduce point and non-point source pollution loadings to coastal waters.

PENDING LEGISLATION

I would like to conclude with comments on the *Harmful Algal Bloom and Hypoxia Research Amendments Act of 2003*.

My first comment is that I am fully supportive of the effort to expand the national HAB program to include a focus on freshwater HABs. I share the concerns of Dr. Carmichael and many others that freshwater lakes, ponds, and streams are increasingly impacted by blooms of toxic algae, and that these blooms are associated with a significant threat to public health. I need to stress, however, that marine HAB problems are far from resolved, are different in many ways from freshwater systems, and therefore that separate funding programs are needed. We must add freshwater HAB research to the national agenda, not replace marine programs with new initiatives focused on freshwater. I realize this is not the intention of the *Harmful Algal Bloom and Hypoxia Research Amendments Act of 2003,* but difficult choices will likely arise if new funding resources are not appropriated for freshwater HAB research.

Second, I support the need for scientific assessments on freshwater HABs, on a research plan to reduce impacts from HABs, and on hypoxia. The freshwater assessment is new and necessary for program development and implementation, an update on the hypoxia issue is timely, and a new report that drives the implementation of a prevention, control and mitigation program for HABs is needed as well. My only comment here is that the Task Force specified in the legislation is composed entirely of federal agency representatives. There is considerable expertise and perspective to be gained by formally including some academic partners in the assessment effort.

I concur with the need for regional scientific assessments of hypoxia and HABs, but am not convinced that local assessments are needed. The HAB problem is quite diverse, with many different toxic organisms, affected resources, and affected regions. Many of these blooms transcend jurisdictional boundaries separating states or other entities. If assessments are requested at a scale below the regional level, inefficiencies and redundancies will result, and resources and personnel to conduct those assessments may be stretched too thin.

Finally, I want to re-emphasize the need for appropriations that are commensurate with the scale of this reauthorization. The national HAB program is well-established and productive, but it needs additional resources if new topics, responsibilities and tasks are added through this legislation.

Mr. Chairman, that concludes my testimony. Thank you for the opportunity to offer information that is based on my own research and policy activities, as well as on the collective wisdom and creativity of numerous colleagues in the HAB field. I would be pleased to answer any questions that you or other members may have.

Respectfully submitted,

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Recipient, Stanley W. Watson Chair for Excellence in Oceanography, 1993
Recipient, NOAA Environmental Hero Award (1999)
Director, NATO Advanced Study Institute on the Physiological Ecology of Harmful Algal Blooms, Bermuda, 1996.
Chairman, SCOR Working Group on Harmful Algal Blooms (1992-1996)
Director, U.S. National Office on Marine Biotoxins and Harmful Algal Blooms (1993-present)
Scientific Advisor, U.S. Delegation to the IOC/FAO Intergovernmental Panel on Harmful Algal Blooms (1992-present)
Fellow, Cooperative Institute for Climate and Ocean Research (CICOR), a Joint Institute of the Woods Hole Oceanographic Institution and the National Oceanic and Atmospheric Administration (1999-present)
Member, Scientific Steering Committee, GEOHAB (The Global Ecology and Oceanography of Harmful Algal Blooms) (1998-present)
Member, NRC Committee on the Causes and Management of Coastal Eutrophication
International Organizing Committee, Toxic Marine Phytoplankton Conferences (1989-present)
Testimony before the Subcommittee on Oceans and Fisheries of the Committee on Commerce, Science, and Transportation, United States Senate 105th Congress, Second Session, May 20, 1998.

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Chairman, Ad Hoc Group of Experts on Harmful Algal Blooms, Intergovernmental Oceanographic Commission (1989)

U.S. Representative, Working Group on Phytoplankton and Management of their Impacts, International Council for Exploration of the Seas (ICES) (1989-present)

U.S. Representative, WESTPAC Task Team on Red Tides, Intergovernmental Oceanographic Commission (1985 - present).

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